Coastal Area Tactical-mapping System (CATS)

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LONG-TERM GOALS

The long-term goals of the CATS project are:

(1) to improve detection and identification of anti-vehicle and anti-personnel obstacles and munitions in the coastal zone, and

(2) to gain a fundamental understanding of the low-energy lidar phenomenology of the earth's surface, near-shore coastal environments, and vegetation foliage.

OBJECTIVES

The overarching objective of the CATS project is to design, build, and demonstrate a low-power scanning airborne laser altimeter capable of continuous ground coverage, superior three-dimensional (3D) sampling, and shallow-water penetration.

APPROACH

As a result of a no-cost extension from ONR through March, 2007, re-targeting of available funds, and allocation of internal funds (non-ONR), significant progress has been made towards the goal of getting the CATS system airborne. UF and subcontractor personnel have worked together to address issues that were unresolved at the time of the last progress report. Several aspects of system operation have been improved, such as photomultiplier tube protection and alignment and USB adapter function. System testing has revolved mainly around the timetag system used in the creation of range data files and the evaluation of system performance. The key individuals participating in this work are listed in Table 1.

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Table 1: Key individuals participating in CATS and their roles

Name	*Organization*	*Role*
Ramesh Shrestha	UF	PI: Programmatic, fiscal
Clint Slatton	UF	Co-I: Design, sensor modeling
Bill Carter	UF	Design, systems engineering, oversight of integration and testing
John Degnan	Sigma Space, Inc.	Detailed design of optical-mechanical and laser subsystems, system-level integration
Bill Gavert	Fibertek, Inc.	Detailed design and testing of receiver subsystem

WORK COMPLETED / RESULTS

Shutter implementation:

Previously, a protective film was placed over the face of the photomultiplier tube (PMT) to ensure that the tube would not be exposed to unnecessary ambient light when not in use. This practice served to maintain the tube's sensitivity and extend the lifetime of the instrument. The removal of the protective film was, however, a time-consuming process as the unit had to be opened in a clean lab environment before every data collection. The process was also impractical for operators in the field. As a permanent solution, an internal mechanical shutter was installed to seal off input to the photomultiplier tube. This shutter is a DC-powered device with a solid-state relay driven by 5 V. For simple operation, control of this relay is connected to one of the eight general purpose digital output lines on the Galil motion control board. In software, these lines can be pushed high by setting a bit via an output port, and returned to zero by clearing the same bit. The shutter is thus easily controlled by the system operator, and can be opened directly prior to data collection (i.e. after scan patterns have been set) and closed after collection is complete. The ease of system setup and the expected lifetime of the tube are improved with the implementation of this component.

Channel uniformity analysis:

As shown in our previous annual progress report, the distribution of returns from a bank building during rooftop tests showed significant sensitivity level differences per channel. Patterns in return levels suggested that the physical alignment of the detector may have been off. It was decided that the entire PMT needed to be moved downward a distance equal to one row in its 10×10 array (see Fig. 1). Sigma Space personnel removed the telephoto assembly and tip-tilt mirror leading to the detector face. The detector face was covered with shims and white paper while marking the current x and y locations of the top rows. By adjusting the tip/tilt mirror on the receive side, the array was translated one row downward towards the optical bench. Fibertek personnel tested the detector output under a low-power, constant illumination source in the lab, and adjusted individual channel gains to produce nearly equalized outputs across all channels. UF personnel then traveled to Lanham, MD on March 20th, 2007 to perform tests with the newly aligned instrument on the roof of the Sigma Space building. Post-processing of return data, however, was inconclusive as to whether the uniformity had improved as a result of alignment. Static data from post-alignment drywall and brick tests at 250 meters (March 29th) did not yield logical results in comparison to pre-alignment tests (March 23rd). Analysis of returns from post-alignment horizontal and vertical scans followed a more logical pattern, but this was

not the ideal data with which to evaluate channel-to-channel performance. Another static test was proposed.

Timetag system structure:

A more fundamental issue surfaced during analysis of post-alignment scan data: data processing was not able to reliably predict the shot number that corresponds to the start of a scan period. It should be possible to calculate the timetag of each shot number through combination of the local 1 MHz counter value in the range file and the current time value in the internal clock file (I.STD) file. A direct comparison to the timetag of the scanner index wedge times should then yield the shot number that corresponds to the start of a scan period. This did not turn out to be true. The point clouds derived from these predicted 'first' shots had the forescans and backscans mis-aligned. Only when the 'first' shot number was shifted (by anywhere from 20 to 350 shots) was the proper point cloud generated. To examine the problem, the basic structure of the GPS timetagging done by Fibertek was analyzed by UF personnel. Each individual data collection resulted in the output of 4 relevant timing files. They are as follows:

A.STD: The time at which the A-Scan Wedge index mark was detected. This is recorded as a coarse time (seconds) and a fine time (microseconds).

B.STD: The time at which the B-Scan Wedge index mark was detected. This is recorded as a coarse time (seconds) and a fine time (microseconds).

Ranges.SPR: Contains all relevant ranging information (channel #, range bin, etc.). This file also contains the output value of a 1 MHz microsecond counter which is reset every 100 Hz. This is the only time information individually recorded for every shot.

I.STD: An internal system clock that is updated when the 100 Hz reset signal is fired. This file also contains information about coarse time read from a GPS 1 Hz signal.

The timing protocol involves matching the microsecond counter value in the Ranges.SPR file to the appropriate time in the I.STD file. The resulting shot time tag is:

The position in the I.STD file is incremented when a 100 Hz reset in the Ranges.SPR file is detected. Shot time tags are matched up with either the A.STD or B.STD times to get the shot that corresponds to the start of a scan period (hereon be called shot0). The difference between shot time tags and the first A-index time was used to determine shot0.

Given this basic structure, a number of issues identified in the individual timing files could have contributed to the difficulties of predicting shot0. A series of data from the March 20th tests showed that the 100 Hz micro-second counter reset was often missed, causing gaps in the I.STD data as well as microsecond counter values in the range data file that exceeded 10000 (see Figs. 2 and 3). There were also aberrations in the microsecond counter value where the increment from one shot to the next was 2-3 times the normal value (implying dropped shots). Additionally, the number of entries in the I.STD data file did not match the number of resets detected from the 1 MHz counter in the range data file. At

this point UF personnel came to the conclusion that the timetag system had to undergo significant testing and potential redesign. Meetings were arranged in Fairfax, VA to aid Fibertek personnel.

Timetag hardware analysis:

The logic for timetag operations is contained within a Xilinx FPGA (see Fig. 4). Index mark timetags are produced as a result of four input pins tied to the following signals: 1) 1 Hz GPS signal, 2) a free running counter based on a local 1 MHz oscillator, 3) the A-scan index mark signal, and 4) the B-scan index mark signal. The leading edge of a pulse detected on pins 3 or 4 generates an interrupt which latches in data from the stored GPS time (updated every second via a signal on the first pin) plus the current value of the free-running counter. The GPS signal serves as a reset for the 1 MHz counter so that it does not overflow. The files A.STD and B.STD are generated by this process.

Shot timetags are created by essentially the same method, but using a different fine precision counter. This method uses a different 1 MHz local oscillator from inside the main electronics "cube" rather than index mark oscillator, which is on the controller board itself. The microsecond counter is reset by a 100 Hz internal signal, found in I.STD. The value of the counter is matched to the appropriate time in the I.STD file to create the shot timetag as previously described.

In reference to the problem of determining shot0, questions were raised about the synchronization between the two different local oscillators. Fibertek suggested that the accuracy of the sync might be related to the throughput capacity of the USB link versus the Ethernet link due to the control loops routing certain signals. High load conditions could produce an offset that would create a disparity in the calculated shot0 offset. To solve this potential problem, it was suggested to directly input the laser fire pulse train into the FPGA used to tag the index mark signals. A new output file in the same format as the index mark files could then be created to record the shot timetags. This slight redesign of the timetag system required modification of the FPGA programming and signal routing.

UF personnel traveled to Fairfax, VA on July 13th, 2007 to test the new timetag structure. The unit was set up on a tripod in the parking lot outside of the Fibertek main building. Data collections with the sensor pointed at a building edge in the distance provided point cloud data with distinct geometries, allowing for the characterization of scanner behavior for consecutive 400 shot periods. Assuming that all other aspects of the system were working correctly, timetag files were compared to determine shot0 for each data set. Out of 11 data sets, 9 registered the correct value of shot0.

During system testing to evaluate the new timetag structure, the scanner exhibited some unintended movement errors visible to the eye that had not occurred on previous tests. For example, during night operation of a static horizontal line scan, the observed output pattern began to slowly rotate such that the pattern eventually became vertical. These rotations did not occur throughout all conducted trials, so a second round of tests in the Fibertek parking lot was conducted on August 16th, 2007. The same large-scale scanner error was observed, and further post-processing of timing data collected during aberrant scanner behavior showed that the B-scan index timetags changing slowly from trial to trial. It was then theorized that some malfunction of the B-scan wedge was causing the system to produce bad patterns. The system was brought into the lab for oscilloscope observations of diagnostic signals. The period of the A-scan index signal was uniform at about 1.5 microseconds, but the B-scan index signal appeared to fluctuate between 1 and 3 microseconds. The sensor head was then opened for visual inspection of the optical encoders and a large crack was found on the B-scan wedge encoder. This was

definitely the cause of the observed scanner error. On a positive note, the new timetag system correctly identified the problem.

USB control board integration:

Given the amount of lead time necessary to manufacture an optical encoder plate and mount the new plate onto the B-scan wedge, UF and Fibertek made plans for Fibertek to integrate the USB adapter board into the larger electronics cube. The board was previously housed in a separate enclosure connected to the receiver cube by a flex cable. The FPGA used to implement USB board functions was consolidated into a newly designed control board, the manufacture of which will be finished by the time the new encoder plate is completed. The result of this redesign will be a more robust receiver structure that is less prone to reset conditions and requires less external wiring.

IMPACT / APPLICATIONS

A correctly operating timetag structure is a significant part of the CATS unit design. Without accurate knowledge of when the start of a scan occurs, it would be difficult to align recorded return events to scanner behavior. Since intended targets for airborne operation (e.g. varying terrain with landcover) will not exhibit sufficiently regular geometry to enable manual adjusting to align the scans, it is essential that a correct shot0 is calculated. Timetag comparison also allows for the diagnosis of potential problems with individual system components. For example, laser double pulsing can be identified and corrected via post-processing of event time histories.

One conference presentation on CATS was made this year by Kris Shrestha (Univ. of FL) at the American Society for Photogrammetry and Remote Sensing Annual Conference (ASPRS) in Tampa, FL entitled “Receiver Design for a Photon-Counting Airborne Laser Swath Mapping System.” Also, an example of the potential surface resolution obtainable from CATS was simulated for the paper “Airborne laser swath mapping: achieving the resolution and accuracy required for geosurficial research”, by Slatton, Carter, Shrestha, and Dietrich, to appear in late 2007 in Geophysical Research Letters.

TRANSITIONS

RELATED PROJECTS

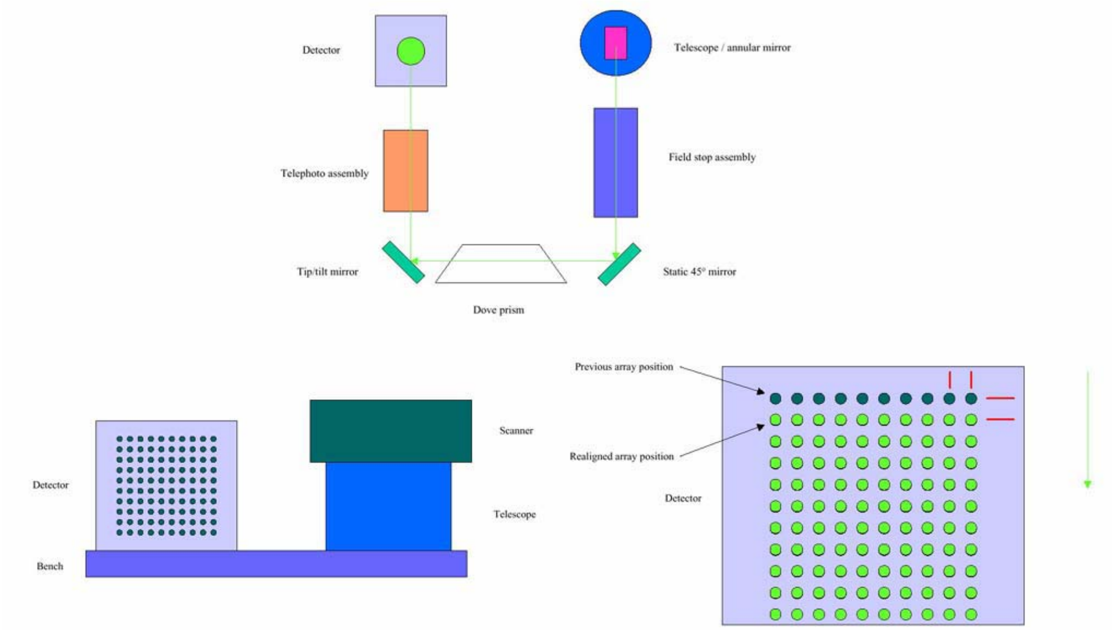

Fig. 1: (Top) Receive path layout of CATS optics. (Bottom left) Receive side looking down at detector. Note, in this sub-figure, the detector is not drawn to scale. (Bottom right) Realignment procedure for detector pixels.

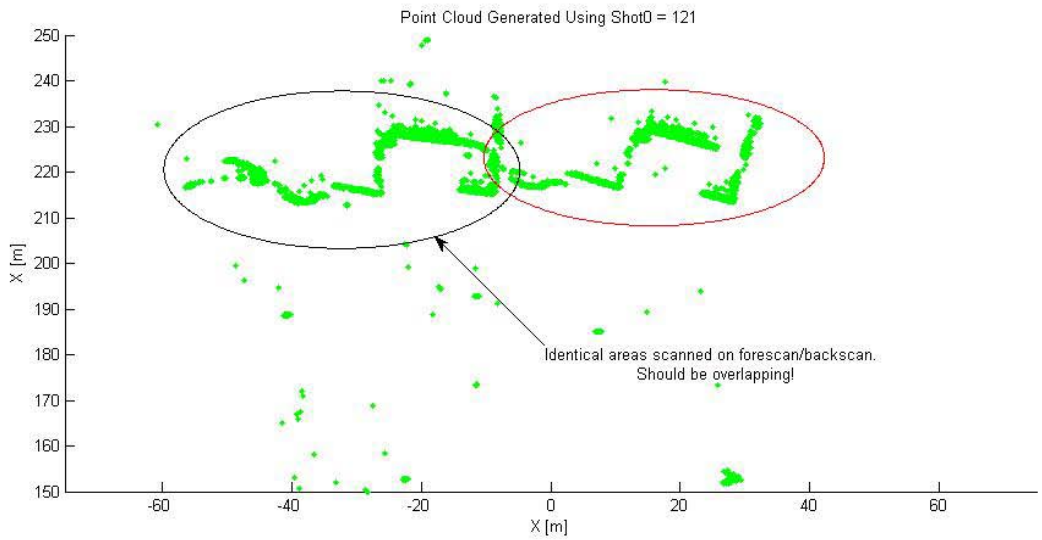

Fig. 2: Point cloud obtained from a horizontal profile scan of a bank building at a range of 250 meters from the top of the Sigma Space roof. The figure was generated using shot0 calculated from GPS timetags. The two highlighted areas represent the same building structure and should overlap, but do not because of the error in shot0 calculation.

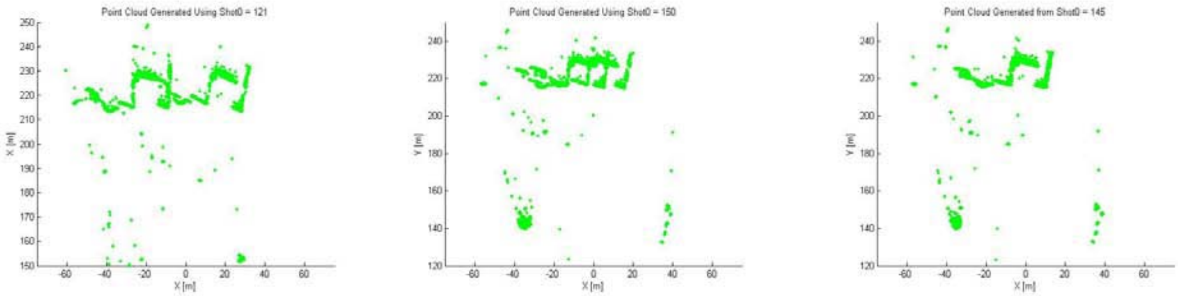

Fig. 3: As shot0 is varied, the forescan (the image produced from the first 200 shots) and the backscan (the image produced from the last 200 shots) begins to align and merge. The figures above shows the point clouds generated using the initial expected shot0 value (Left), shot0 manually set to 150 (Middle), and shot0 manually set to 145 (Right). 145 is the value of shot0 that results in the best point cloud.

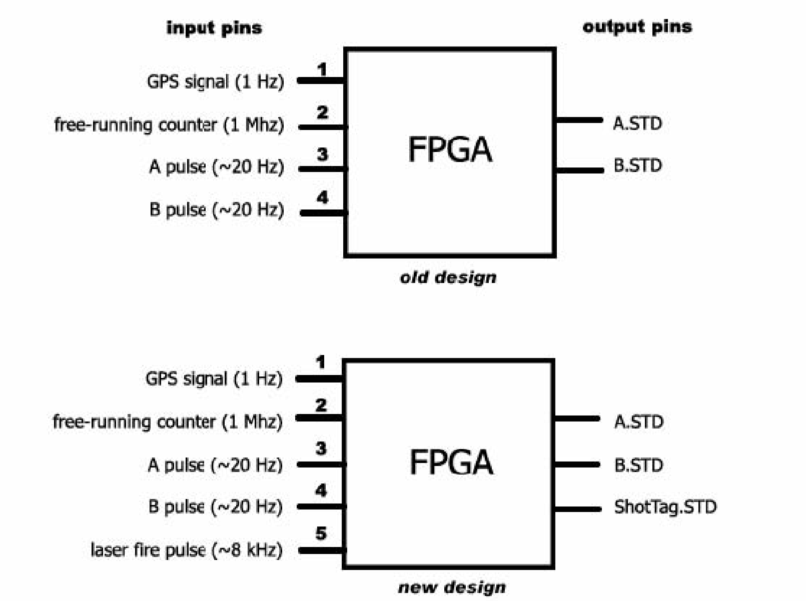

Fig. 4: FPGA block diagram showing redesign of CATS timetag structure to improve calculation of start of scan periods.